Original Research Article

Woody species diversity under the different age of area closure and slope aspects of Boswellia dominated woodland of Kafta Humera, Northern Ethiopia.

Abstract

Area closures have recognized to be the best land management practices for creating economically and ecologically sustainable land use planning. Although the need of scientific information is clear, studies made to assess woody species diversity under the different age of area closure and slope aspect of Boswellia dominated woodland are very limited. This study assesses the woody species composition, diversity, and richness of Boswellia dominated woodland under the different age of area closure and slope aspect. For this study, four slope aspects (east, west, north, and south) and three age (two, five and eight) of area closure and one open land were purposively selected. The present study was conducted in Kaftan Humera, Tigray Region. Vegetation assessment was done using systematic plot sampling and two-way analysis of variance was used to analyze the vegetation data. The results of the study showed that eight years east slope aspect area closure were significantly ($P < 0.05$) higher in species richness (5.25), Margalef index (1.92), Simpson (0.67) and Shannon (1.37) diversity index. However, species evenness was not significantly ($P > 0.05$) differ in all age and slope aspect of the area closures. This suggests that age and slope aspects create plant communities that are quite different on different sides of the mountain of the area closure. Thus, area closures have a considerable contribution in maintaining most importance woody species like *Boswellia papyrifera* from deforestation and land degradation for increasing biodiversity, ecological restoration, and community livelihood improvement.

Key words: Area closure, Slope aspects, Diversity, *Boswellia papyrifera*

1. Introduction

The land degradation that includes the degradation of vegetation cover, nutrient and soil depletion is a major environmental and socioeconomic problem in Ethiopia [1]. For example, [2] estimated that the rate of forest degradation in Ethiopia ranges from 210,000 ha per year. On the other hand, [3] reported that the soil loss of Ethiopia ranges to 35 t ha1 year1 from agricultural steep slopes

(30-50%) in Northern Ethiopia. The capacity of forests and the lands to improve environmental conditions and socio-economic benefits to the people have been reducing from time to time [4].

Land degradation and deforestation caused by heavy livestock grazing pressure and encroachment subsistence cultivation are proximate causes for severe dryland degradation in many parts generally in Ethiopia particularly in Tigray [5-7]. However, Tigray is known not only for the severity of land degradation but also for concentrate efforts taking place since the 1970s, to rehabilitate the region through land rehabilitation techniques such as stone terraces, soil bunds, area closure and afforestation [8].

Many studies in Ethiopia have pointed out that excluding of human and animal interferences from the degraded hillside areas can contribute to advance rehabilitation of degraded lands and socio-economic benefits to the local communities [7, 9-13]. Following establishment, the vegetation recovery process in area closure consistently starts with the rapid recovery of herbaceous species. After three to five years, shrub and tree species gain importance and suppress the abundance of herbaceous species [14]. However, in Tigray, few studies on the impact of area closure on ecological restoration and on its buffering, effect were conducted in the recent past in different parts of the region [5, 14-16].

Area closure are the type of land management practices which implemented for environmental restoration with a clear biophysical influence on large parts of the degraded land [17]. Studies indicated that land degradation affects the composition, structure, diversity and landscape pattern of vegetation [18, 19]. Therefore, restoration of plant diversity is an important land management tool to rehabilitating degraded landscapes [20, 21].

Several case studies conducted in the central and northern highlands [7, 12, 22, 23] and southern lowlands [24] of Ethiopia have shown that area closure can be effective in enhancing composition, diversity, and density of vegetation. Accordingly, assumption when conducting the present study was the region has diverse climatic and soil conditions as well as substantial cultural differences in natural resource management, and conclusions about the impact of area closure on ecological restoration cannot be drawn from these few studies with limited geographical coverage.

2. Materials and Methods

2.1. Study area

The study was conducted in the dry forests of western zones of Tigray regional state, where *Boswellia papyrifera* naturally exist. Plains and rugged topography characterize the relief of their agro-ecologies, which includes hot to warm semiarid low lands, hot to warm sub-moist low lands and river gorges and tepid to cool sub-moist mid-highlands, mountainous and plateau. These areas are also relatively sparsely populated [25].

The dry forests of western Tigray are rich in natural trees and shrubs. Most shrubs and trees of the area are deciduous and xerophytes in nature that have an adaptation to the limited rainfall and prolonged dry season. The *Boswellia, Commiphera*, and *Sterculia* species are found on slopes that are relatively steep with an average slope of 30–50% and covering hillsides and river basins.

Kafta Humera district is located in north-western Ethiopia and in the western part of Tigray Regional State with a total land area of 632,877.75 ha which is about 23.6 percent of the western zone of Tigray is located between 36^0 27’ 5’’ to 370 33’ 7’’ E and from 13^0 39’ 46’’ to 14^0 26’ 35’’N (Figure 1). it is located 991 km away from Addis Ababa.

Kafta Humera has dominated by early tertiary volcanic and Precambrian rocks and also the dominant soil types in the study area are chromic eutric and calcic combisols; chromic and orthic luvisols and chromic and pellic vertisols within an altitude range of 560- 1849 meter above sea level. The mean total rainfall ranges from 400-650 mm. The mean maximum temperature varied between 33^0C in April and 41.7^0C in May, while the mean minimum temperature is between 17.5^0C in August and 22.2^0C in July. The rainy season of the study area is from June to September. The remaining 8-9 months between October and May/June is dry and hot [26].

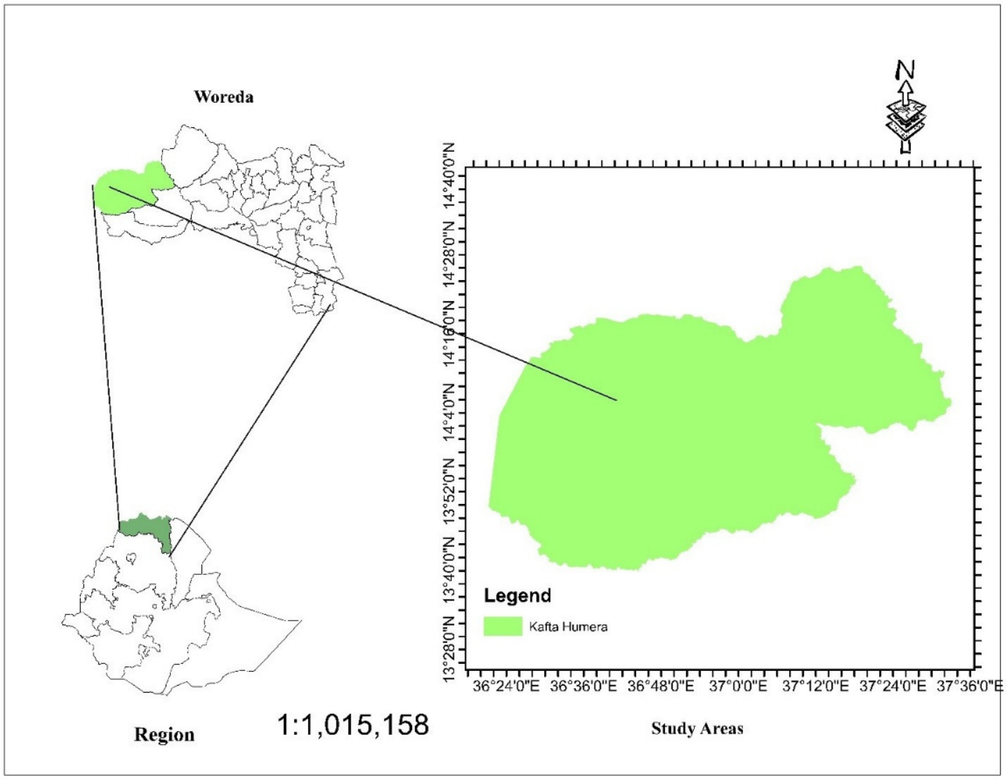

Figure 1. Study sites of Kafta Humera, the western zone of Tigray, Northern Ethiopia

2.2. Data Collection Methods

2.2.1. Sampling Techniques: The sampling procedures focused on identification of sites having area closure practices on *Boswellia papyrifera* dominated woodland. Accordingly, four ages of area closure were purposively selected. Since the study was made different years after the establishment of area closure, it was not possible to fully explain the process in the vegetation dynamics. But changes after the establishment of area closure could be described using some important parameters. Finally, according to the ages of area closure and slope aspect, the first sample quadrats measuring 20m X 20 m (400 m2) was laid randomly, following systematic sampling procedure with 100m interval between quadrats of the same transect and 200 m apart from each transect line for data collection (Mengistu et al., 2005, Abesha, 2014). A total of 128 quadrants, 32 quadrats in each selected area closure, were used for vegetation inventory. Woody vegetation within the sample plots was also recorded by vernacular names and finally reported using their respective scientific names. All Scientific names followed [27-30].

2.2.2. Sampling Design: For the assessment of the diversity of woody species in the area closure, all woody species were recorded, and diameters at breast height (DBH, 1.3 m) were measured using a caliper or diameter tape [31]. Within the quadrats, five subplots of 5 × 5 m, at five corners and in the center, were laid for sapling assessment for the diameter of 1–5 cm. Within each subplot, again a small five plot of 1 × 1 m was laid in each corner and center for seedling assessment for diameter <1 cm [7, 31].

2.3. Data Analysis

2.3.1. Woody Species Diversity Indices: Woody species diversity was analyzed by using different diversity indices. Shannon diversity index (H'), Shannon equitability/evenness index (E), species richness (S) and Simpson diversity index (D) was calculated and analyzed. These diversity indices provide important information about scarcity and commonness of species in a community. Species richness is the total number of species per community [32].

Species richness: Species richness is a biologically appropriate measure of alpha (α) diversity and the total number of species in an ecological community, landscape or region relative to the total number of all individuals in that community and can be calculated by using Margalef's index of richness (D_{mg}) [33].

$$D_{mg} = \frac{S-1}{\ln N} \text{ .... (equation 10)}$$

Where: S is Total number of species, N is Total number of individuals in a sample

Shannon-Wiener Diversity Index (H'): Shannon's index measures through a combination of species richness and evenness [32, 34, 35]. The Shannon diversity index is higher when the number of individuals of the different species is even and is low when few species are more dominant. The Shannon diversity index is calculated as follows:

$$H' = -\sum_{i=1}^{s} Pi \ln Pi \text{ .... (equation 1)}$$

where H' is Shannon diversity index and Pi is proportion n of individuals found in the i^{th} species.

Evenness (Shannon equitability) index (E): was calculated as described by Taylor [36] to estimate the homogeneous distribution of tree species:

$$E = \frac{\sum_{i=1}^{n} Pi\ ln\ Pi}{\ln S} = \frac{H\prime}{\ln S} \text{.. (equation 11)}$$

Where: S is the number of species and Pi is the proportion of individuals of the i^{th} species or the proportion of the total species. E has values between 0 and 1, with 1 being complete evenness [36].

Simpson's Diversity Index (D): Simpson's diversity index is derived from a probability theory and it is the probability of picking two different species at random [32-34]. Simpson's diversity (D) is calculated as.

$$D = 1 - \sum_{i=1}^{s} P_i^2 \text{.. (eq. 3)}$$

Were D is Simpson's diversity index, Pi is the proportion of individuals of the i^{th} species.

Simpson's diversity index gives relatively little weight to the rare species and more weight to the most abundant species. It ranges in value from 0 (low diversity) to a maximum of (1 − 1/S) where S is the number of species [32, 34].

Frequency (F) - the proportion of quadrats in which a species found. The frequency value reflects the pattern of distribution and expressed as number of quadrats in which species recorded per total number of quadrats as a percentage [37].

$$F = \frac{The\ numbers\ of\ quadrats\ in\ which\ the\ species\ occur}{Total\ quadrts\ laid}\ X\ 100$$

Rarefaction and species accumulation curves: Since number of species is highly dependent on sample size, comparing communities having different sample size is problematic [38]. Hence to overcome this problem, all samples from different communities should be standardized to a common sample size of the same number of individuals. [39] proposed rarefaction method for achieving this goal. Rarefaction is a statistical method for estimation of the number of species expected in a random sample of individuals taken from a collection.

In this study, sample-based rarefaction curves [40] were computed using EstimateS version 9.1.0, to compare the species richness of these area closure. To evaluate the effectiveness of the species estimators and to examine the degree of species collection (sampling) species accumulation curve was also plotted.

2.4. Statistical Analysis: Variation in woody species diversity was tested using Two-way ANOVA. A significant difference in mean values for woody species diversity was tested by the least significant difference at P< 0.05. All statistical computations were made using R statistical Software version 3.4.3.

3. Results and Discussions

3.1. Composition of above-ground woody vegetation: A total of 22 woody species belonging to 13 families were gathered, identified and recorded in the Boswellia dominated area closure of the study sites (Table 1). All of the woody species in the area closure were indigenous species. The eight-year-old area closure had 21 woody species. Among the species encountered, 16 were recorded in all ages of area closure. Combretaceae (5), Papilionoideae (4) and Fabaceae (3) family had the highest number of woody species, while Anacardiaceae, Balanitaceae, Bignoniaceae, Bombacaceae, Burseraceae, Euphorbiaceae, Mimosoideae, Moraceae, Rubiaceae, and Tiliaceae families had the lowest number of woody species (1 each). There were 19, 19 and 18 woody species in the five years old area closure as well as the two years old area closure and open land, respectively. The species composition increases with the increased age of area closure. This could be explained by the disturbance created by humans and livestock was minimizes.

Table 1. Species composition of area closures

SN	Local Name	Scientific Name	Family name	status
1	Chea	***Acacia nilotica***	Mimosoideae	Indigenous
2	Gumero	***Acacia polyacantha***	Fabaceae	Indigenous
3	Dimma	***Adansonia digitata***	Bombacaceae	Indigenous

4	Hanse	***Anogeissus leiocarpus***	Combretaceae	Indigenous
5	Mekie	***Balanites aegyptiaca***	Balanitaceae	Indigenous
6	Meqer	***Boswellia papyrifera***	Burseraceae	Indigenous
7	Weiba	***Combretum molle***	Combretaceae	Indigenous
8	Tenkeleba	***Combretum fragrans***	Combretaceae	Indigenous
9	Akumma	***Combretum spp.***	Combretaceae	Indigenous
10	Zibbe	***Dalbergia melanoxylon***	Papilionoideae	Indigenous
11	Ziwaw'e	***Erythrina abyssinica***	Papilionoideae	Indigenous
12	Afekemo	***Ficus hochstetteri***	Moraceae	Indigenous
13	Hatsinay	***Gardenia lutea***	Rubiaceae	Indigenous
14	Mesequa	***Grewia bicolor***	Tiliaceae	Indigenous
15	Dugdugunga	***Lannea fruticosa***	Anacardiaceae	Indigenous
16	Dengerifa	***Lonchocarpus bussei***	Papilionoideae	Indigenous
17	Alendia	***Ormocarpum pubescens***	Papilionoideae	Indigenous
18	Tsara	***Pterocarpus leucens***	Fabaceae	Indigenous
19	Harmazo/Ayehaday/	***Securinega virosa***	Euphorbiaceae	Indigenous
20	Adgi-Zana	***Stereospermum Kunthianum***	Bignoniaceae	Indigenous
21	Humer	***Tamarindus indica***	Fabaceae	Indigenous
22	Weiyba	***Terminalia brownii***	Combretaceae	Indigenous

3.2. Density of woody plants: The densities of all woody plants in the open land, two, five and eight ages of area closure were 359, 628, 743 and 508 individuals/ha, respectively (Table 3). The pioneer species, *Boswellia papyrifera*, that accounts for 100 % of the density of woody plants dominated in all of the area closure followed by *Anogeissus leiocarpus* and *Acacia nilotica.*

3.3. Woody Species Richness and Diversity indices: The number of woody species richness and margalef richness index computed for the three area closures and open-grazed land. The result indicated that all area closures showed greater species richness when compared to the open land. The highest value being 5.25 recorded for the area closure of age 8yrs east aspect (Table 3) which was almost twice to that of the open land east aspects. This implies in general, that species richness increases in area closures than in the open grazed lands (Table 2). As shown in Table 2 the species richness increases with the age of area closure and slope facing have also significant effect. This showed that the species richness of the study area depends on the age of area closure and slope aspects. The variation could arise from the local difference in biophysical factors and also the effectiveness of the management. [41-43] have also observed that differences in microclimate and the effectiveness of management resulted in a difference in species richness. It is also indicated that anthropogenic disturbance, as measured along the disturbance gradient, clearly affects species composition of many of the plant communities [44].

Shannon-Wiener's diversity index indicated that the eight-year east slope aspect (slope facing) age of area closure was significantly more diverse (1.37) than the other age of area closure and slope aspect followed by four-year east aspect area closure (1.32) (Table 2). The list value was that of open land and east aspect (0.83). This could be explained by the difference in the degree of heterogeneity within the sites. For example, sites like the eight-year east aspect of area closure (which are heterogeneous) can support more woody species than others with less heterogeneity.

Simpson's diversity index (D) that measures the dominance of the species is shown in Table 2. Accordingly, the Eight-year east aspect area closure had significantly highest (0.67) value. The least value was for the open land east slope aspects (0.49). The differences might be due to the variation in a number of individuals that represent each species within the respective age classes and aspects.

Table 2. Woody species diversity in Boswellia dominated exclosure of Kafta Humera, Northern Ethiopia

Year	Diversity Measurement				
	Species richness (S)	Margalef richness index (D_{mg})	Simpson diversity index (D)	Shannon diversity index (H')	Shannon evenness index (E)
8 Year * East	5.25 ± 0.75^{b}	1.92 ± 0.29^{d}	0.67 ± 0.05^{b}	1.37 ± 0.16^{b}	0.85 ± 0.03
8 Year * North	4.00 ± 0.27^{ab}	1.43 ± 0.22^{abcd}	0.59 ± 0.03^{ab}	1.11 ± 0.07^{ab}	0.81 ± 0.02
8 Year * South	4.50 ± 0.38^{ab}	1.55 ± 0.09^{bcd}	0.61 ± 0.04^{ab}	1.21 ± 0.10^{ab}	0.81 ± 0.03
8 Year * West	4.50 ± 0.27^{ab}	1.62 ± 0.04^{cd}	0.61 ± 0.02^{ab}	1.20 ± 0.06^{ab}	0.80 ± 0.02
5 Year * East	5.13 ± 0.72^{b}	1.48 ± 0.11^{bcd}	0.65 ± 0.05^{ab}	1.32 ± 0.15^{b}	0.85 ± 0.02
5 Year * North	4.00 ± 0.38^{ab}	1.17 ± 0.12^{abc}	0.58 ± 0.02^{ab}	1.08 ± 0.07^{ab}	0.80 ± 0.02
5 Year * South	4.13 ± 0.35^{ab}	1.20 ± 0.18^{abc}	0.63 ± 0.03^{ab}	1.19 ± 0.08^{ab}	0.86 ± 0.02
5 Year * West	4.25 ± 0.31^{ab}	1.29 ± 0.10^{abcd}	0.65 ± 0.02^{ab}	1.22 ± 0.06^{ab}	0.86 ± 0.03
2 Year * East	3.50 ± 0.19^{ab}	0.92 ± 0.10^{ab}	0.56 ± 0.03^{ab}	1.00 ± 0.06^{ab}	0.81 ± 0.04
2 Year * North	3.75 ± 0.31^{ab}	1.05 ± 0.10^{abc}	0.52 ± 0.04^{ab}	0.97 ± 0.09^{ab}	0.74 ± 0.04
2 Year * South	4.63 ± 0.26^{ab}	1.37 ± 0.08^{abcd}	0.62 ± 0.03^{ab}	1.21 ± 0.07^{ab}	0.80 ± 0.03
2 Year * West	4.38 ± 0.26^{ab}	1.17 ± 0.09^{abc}	0.63 ± 0.03^{ab}	1.21 ± 0.07^{ab}	0.82 ± 0.04
Open land * East	2.88 ± 0.23^{a}	0.77 ± 0.14^{a}	0.49 ± 0.04^{a}	0.83 ± 0.08^{a}	0.80 ± 0.03
Open land * North	4.75 ± 0.53^{ab}	1.37 ± 0.14^{abcd}	0.64 ± 0.04^{ab}	1.27 ± 0.11^{ab}	0.83 ± 0.02
Open land * South	4.13 ± 0.30^{ab}	1.19 ± 0.08^{abc}	0.59 ± 0.03^{ab}	1.11 ± 0.06^{ab}	0.80 ± 0.03
Open land * West	3.88 ± 0.23^{ab}	1.04 ± 0.09^{abc}	0.59 ± 0.03^{ab}	1.09 ± 0.06^{ab}	0.81 ± 0.03

F-Value	2.974	2.803	2.257	2.79	0.788
Pr(>F)	0.00328 **	0.00527 **	0.0232 *	0.00546 **	0.628

Mean (±standard deviation, n=32) diversity measurement for the exclosure and results of Two-way ANOVA (at α=0.05, significant differences between age and slope aspects of the exclosures for any of the diversity measurement were indicated)

The parameter estimates for management were consistently negative and significant (Table 2). The decline in species diversity in the open lands can be attributed to the effect of disturbances regime, overgrazing by livestock and human exploitation of vegetation resource for fuel and construction. Chronic herbivory can change composition, structure, and production of plant communities (habitat). With a decline in habitat diversity a concomitant decline in species diversity can be expected. The microenvironment of the degraded land ecosystem becomes gradually hostile for perennial plant species and favorable for annual or short-lived species as the soil becomes thin and divested of its nutrients over time. Eventually, entire absence of perennial plants can result in decline in species diversity as degradation of soil condition progresses. This reduction in plant cover coupled with soil disturbance from animal trafficking provides the potential for invasion of undesirable exotic plant species. Therefore, there is a possibility for some species to decline due to a reduction in habitat required by them. Similarly, some new species may colonize because new habitats are created, and still others may be unaffected.

Asefa, Oba [14] have also reported area closures are significant effect on woody species diversity. Pandey and Singh (1991) who worked on grazing lands in India, have reported that biomass was highest at area closure and decreased with increasing grazing intensity.

Shannon evenness indicated that the highest homogeneity of woody species was found in five-year east aspect of area closure (86%) and west slope aspect (86%) compared with the other age of area closure and slope aspects.

Table 3. List of woody species recorded at Kafta Humera Exclosure with their densities and frequencies

S/N	Species	Life form	Zero Year		Two Year		Four Year		Eight Year	
			Density	Frequency	Density	Frequency	Density	Frequency	Density	Frequency
1	*Acacia nilotica*	Tree	45	56	70	50	68	50	25	28
2	*Acacia polyacantha*	Tree	5	6	33	16	20	13	5	6
3	*Adansonia digitata*	Tree	-	-	-	-	3	3	10	13
4	*Anogeissus leiocarpus*	Tree	48	59	78	47	113	44	45	44
5	*Balanites aegyptiaca*	Tree	-	-	-	-	33	25	28	31
6	*Boswellia papyrifera*	Tree	110	100	140	100	178	97	185	100
7	*Combretum fragrans*	Shrub/tree	8	9	-	-	-	-	5	3
8	*Combretum molle*	Tree	25	31	55	38	48	34	18	22
9	*Combretum spp.*	Shrub/tree	28	34	40	25	45	34	30	31
10	*Dalbergia melanoxylon*	Tree	8	9	20	9	23	9	10	13
11	*Erythrina abyssinica*	Tree	3	3	18	9	15	13	13	16
12	*Ficus hochstetteri*	Tree	10	13	15	9	23	16	20	22
13	*Gardenia lutea*	Tree	-	-	8	3	-	-	10	13
14	*Grewia bicolor*	Shrub/tree	8	9	8	3	-	-	-	-
15	*Lannea fruticosa*	Tree	-	-	18	6	10	6	10	13
16	*Lonchocarpus bussei*	Tree	5	6	13	9	18	9	10	13
17	*Ormocarpum pubescens*	Shrub/tree	13	16	18	16	28	13	8	9
18	*Pterocarpus leucens*	Tree	5	6	40	19	25	19	35	31
19	*Securinega virosa*	Shrub	10	13	28	16	30	19	13	16
20	*Stereospermum Kunthianum*	Tree	5	6	8	3	15	6	10	13
21	*Tamarindus indica*	Tree	10	13	13	9	33	19	10	13
22	*Terminalia brownii*	Tree	13	16	5	3	15	9	8	9
	Total		359		628		743		508	

*Where: F (%) = frequency (number of quadrates occurrence/total number of quadrates *100), D/ha = Density per hectares*

3.4. Species accumulation curves

Rarefaction curve is useful to test whether there is significance difference in species richness between different sites or not. As it was depicted in Fig. 2, 3, 4, 5, the observed species accumulation curve of open land, two and five age of area closure was outside of the 95% confidence eight years area closure revealing that they had significantly higher species richness than that of the other age of area closure.

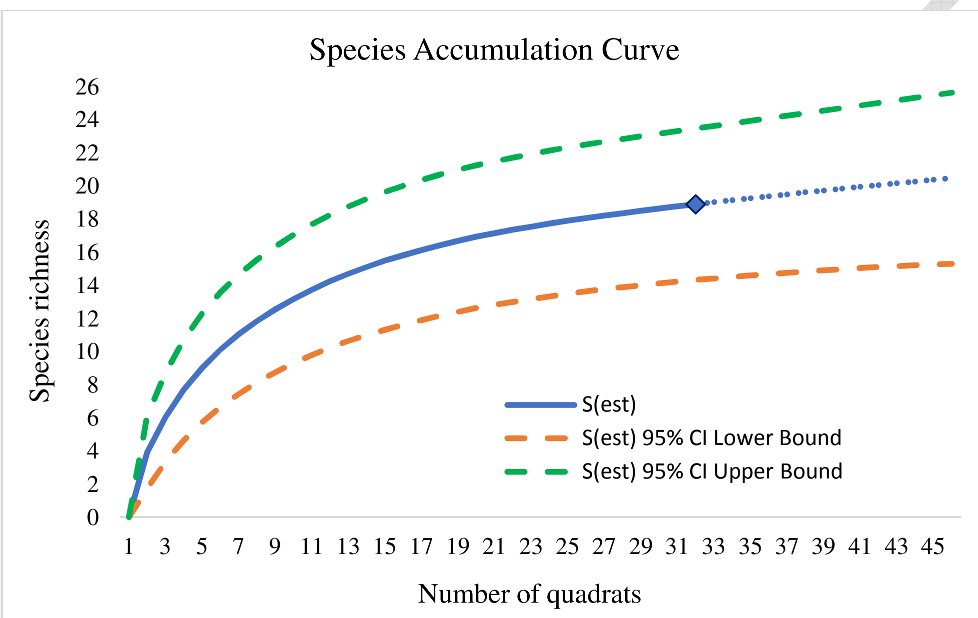

Figure 2. Sample-based rarefaction (interpolated species accumulation) curves for open land. Expected species richness values (solid lines) were computed using the moment-based estimator with 95% confidence intervals (dashed lines).

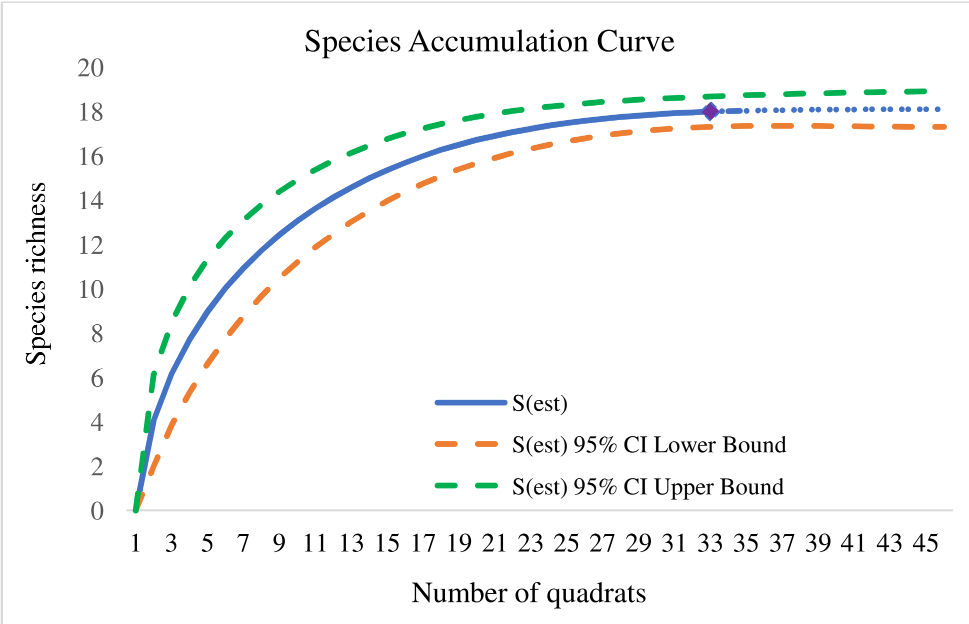

Figure 3. Fig Sample-based rarefaction (interpolated species accumulation) curves for two-year exclosure. Expected species richness values (solid lines) were computed using the moment-based estimator with 95% confidence intervals (dashed lines).

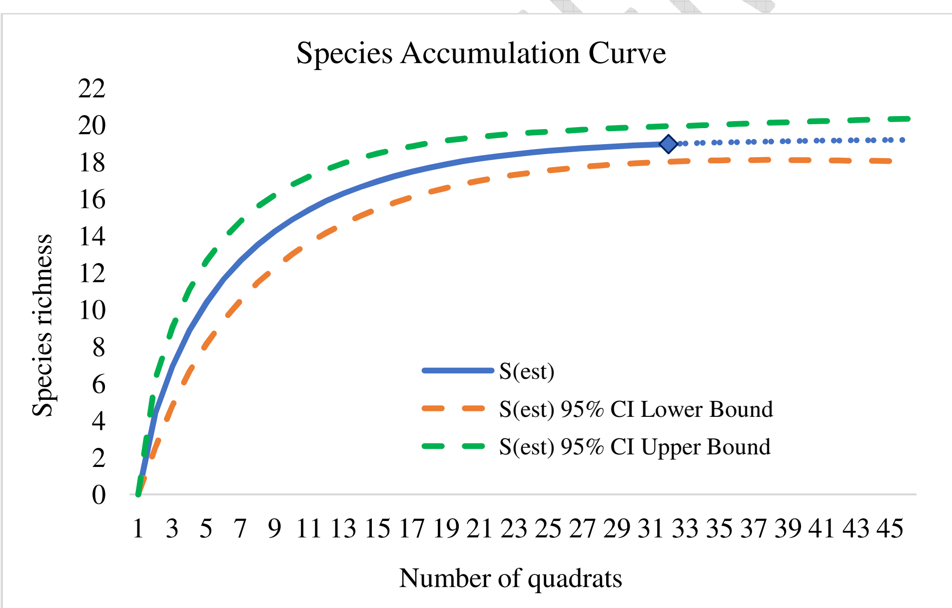

Figure 4. Sample-based rarefaction (interpolated species accumulation) curves for five-year exclosure. Expected species richness values (solid lines) were computed using the moment-based estimator with 95% confidence intervals (dashed lines).

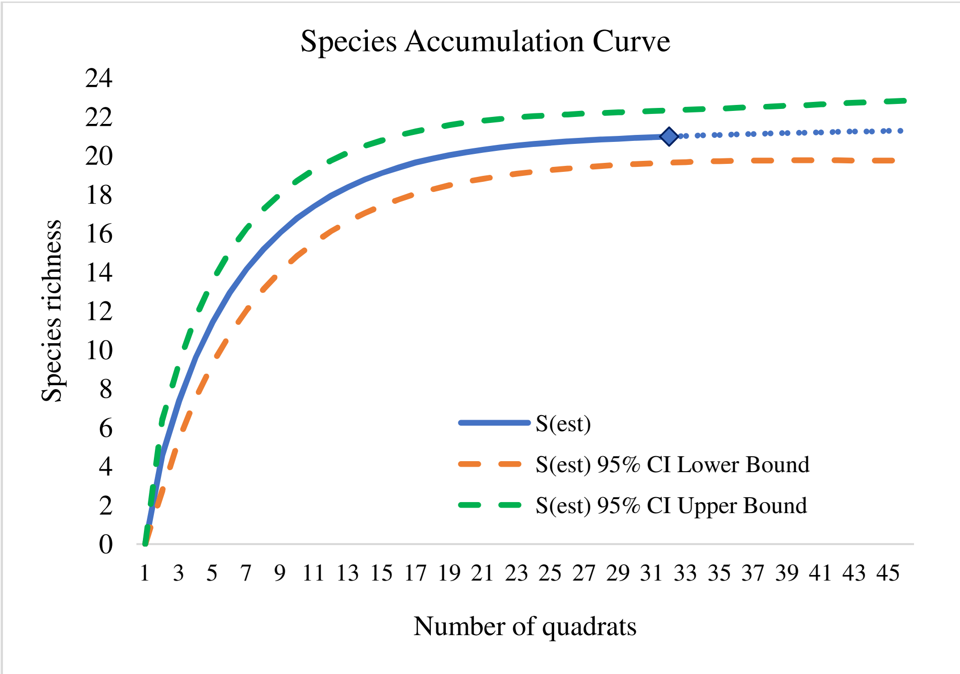

Figure 5. Sample-based rarefaction (interpolated species accumulation) curves for Eight-year exclosure. Expected species richness values (solid lines) were computed using the moment-based estimator with 95% confidence intervals (dashed lines).

4. Conclusion

The study generated empirical evidences, which illustrate the actual and potential role of age of area closure and slope aspect for the recovery of vegetation diversity and land rehabilitation on degraded Boswellia dominated woodlands of the study area. As can be observed from the status of the vegetation in the area closures, it is plausible to conclude that establishing area closure in degraded Boswellia dominated woodlands for vegetation biodiversity conservation and rehabilitation of *Boswellia papyrifera* seem a promising option. It is concluded that such successional sequences and rates of replacement can be regulated to develop biotic communities that meet conservation needs and predict future fate of area closure in the study area.

References

1. Haileslassie, A., et al., *Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances.* Agriculture, ecosystems & environment, 2005. **108**(1): p. 1-16.

2. Forest, M.o.E.a., *Study of Cause of Deforestation and Forest Degradation in Ethiopia and the Identification and Prioritization of Strategic Options to Address those. Addis Ababa, Ethiopia*. 2015.

3. Brhane, G. and K. Mekonen, *Estimating soil loss using Universal Soil Loss Equation (USLE) for soil conservation planning at Medego watershed, Northern Ethiopia.* Journal of American Science, 2009. **5**(1): p. 58-69.

4. Taddese, G., *Land degradation: a challenge to Ethiopia.* Environmental management, 2001. **27**(6): p. 815-824.

5. Aerts, R., et al., *Ecosystem thermal buffer capacity as an indicator of the restoration status of protected areas in the northern Ethiopian highlands.* Restoration Ecology, 2004. **12**(4): p. 586-596.

6. Nyssen, J., et al., *Human impact on the environment in the Ethiopian and Eritrean highlands—a state of the art.* Earth-science reviews, 2004. **64**(3-4): p. 273-320.

7. Mengistu, T., et al., *The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia.* Journal of Arid Environments, 2005. **60**(2): p. 259-281.

8. Hagos, F., J. Pender, and N. Gebreselassie, *Land degradation in the highlands of Tigray and strategies for sustainable land management.* 1999.

9. Tekle, K. and T. Bekele, *The Role of Soil Seed Banks in the Rehabilitation of Degraded Hillslopes in Southern Wello, Ethiopia 1.* Biotropica, 2000. **32**(1): p. 23-32.

10. Birhane, E., *Actual and Potential Contributions of Enclosures to Enhance Biodiversity in Drylands of Eastern Tigray: With Particular Emphasis on Woody Plants*. 2002, Swedish University of Agricultural Sciences.

11. Giday, K., *Woody biomass estimation in community managed closure areas in central Tigray: contributions to sustainable management.* 2002.

12. Yami, M., et al., *Impact of area enclosures on density, diversity, and population structure of woody species: the case of May Ba'ati-Douga Tembien, Tigray, Ethiopia.* Ethiop. J. Nat. Res, 2006. **8**: p. 99-121.

13. Abebe, M.H., et al., *The role of area enclosures and fallow age in the restoration of plant diversity in northern Ethiopia.* African Journal of Ecology, 2006. **44**(4): p. 507-514.

14. Asefa, D., et al., *An assessment of restoration of biodiversity in degraded high mountain grazing lands in northern Ethiopia.* Land degradation & development, 2003. **14**(1): p. 25-38.

15. Gebrehiwot, K., *Ecology and management of Boswellia papyrifera (Del.) Hochst. dry forests in Tigray, Northern Ethiopia*. 2003: Georg-August-University of Gottingen.

16. Descheemaeker, K., et al., *Sediment deposition and pedogenesis in exclosures in the Tigray Highlands, Ethiopia.* Geoderma, 2006. **132**(3-4): p. 291-314.

17. Tucker, N.I. and T.M. Murphy, *The effects of ecological rehabilitation on vegetation recruitment: some observations from the Wet Tropics of North Queensland.* Forest ecology and management, 1997. **99**(1-2): p. 133-152.

18. Matějková, I., R. van Diggelen, and K. Prach, *An attempt to restore a central European species□rich mountain grassland through grazing.* Applied Vegetation Science, 2003. **6**(2): p. 161-168.

19. Walters, D., D. Kotze, and T. O'connor, *Impact of land use on vegetation composition, diversity, and selected soil properties of wetlands in the southern Drakensberg mountains, South Africa.* Wetlands Ecology and Management, 2006. **14**(4): p. 329-348.

20. Aronson, J., et al., *Restoration and rehabilitation of degraded ecosystems in arid and semi□arid lands. II. Case studies in Southern Tunisia, Central Chile and Northern Cameroon.* Restoration ecology, 1993. **1**(3): p. 168-187.

21. Ormerod, S., *Restoration in applied ecology: editor's introduction.* Journal of Applied Ecology, 2003. **40**(1): p. 44-50.

22. Birhane, E., D. Teketay, and P. Barklund, *Enclosures to enhance woody species diversity in the dry lands of eastern Tigray, Ethiopia.* East African Journal of Sciences, 2007. **1**(2): p. 136-147.

23. Yayneshet, T., L. Eik, and S. Moe, *The effects of exclosures in restoring degraded semi-arid vegetation in communal grazing lands in northern Ethiopia.* Journal of Arid Environments, 2009. **73**(4-5): p. 542-549.

24. Angassa, A. and G. Oba, *Effects of grazing pressure, age of enclosures and seasonality on bush cover dynamics and vegetation composition in southern Ethiopia.* Journal of Arid Environments, 2010. **74**(1): p. 111-120.

25. Institute, T.A.R., *Spatial stratification of agro- ecologies in Tigray, Mekelle.* 2002.

26. Gebrewahid, Y., *The effect of age of area closure and slope aspect on aboveground carbon of Boswellia papyrifera dominated woodland of Kafta Humera, Western Tigray, Northern Ethiopia.* J Ecosyst Ecography 7: 235, 2017. **7**(235).
27. Azene, B.-T. and B.a.B.T. Ann, *Shrubs for Ethiopia.* Trees, UsefulIdentification, Propagation and Management for Agricultural and Pastoral Communities. , 1993.
28. Bein, E., et al., *Useful trees and shrubs in Eritrea: identification, propagation and management for agricultural and pastoral communities.* Technical handbook, 1996(12): p. 422.
29. November, E., et al., *Species list Tigrinya–Scientific. Technical note 2002/4*. 2002.
30. Bekele-Tesemma, A. and B. Tengnäs, *Useful trees and shrubs of Ethiopia: identification, propagation, and management for 17 agroclimatic zones*. 2007: RELMA in ICRAF Project, World Agroforestry Centre, Eastern Africa Region.
31. Ponce-Hernandez, R., P. Koohafkan, and J. Antoine, *Assessing carbon stocks and modelling win-win scenarios of carbon sequestration through land-use changes*. Vol. 1. 2004: Food & Agriculture Org.
32. Krebs, C., *Ecological Methodology., 2nd edn.(Addison-Wesley Longman: Menlo Park, CA.)*. 1999, Calif.
33. Magurran, A.E., *Why diversity?*, in *Ecological diversity and its measurement*. 1988, Springer. p. 1-5.
34. Krebs, C.J., *The experimental analysis of distribution and abundance.* Ecology. New York: Harper and Row, 1972.
35. Begon, M., C.R. Townsend, and J.L. Harper, *Ecology: from individuals to ecosystems*. 2006: Blackwell Publishers Hoboken. Australia.
36. Taylor, D., *Vegetation description and analysis: A practical approach*. 1993, JSTOR.
37. Goldsmith, F. and C.M. Harrison, *Description and analysis of vegetation.* Methods in Plant Ecology. SB Chapman, ed, 1976.
38. Magurran, A., *Measuring Biological Diversity*. 2004: Blackwell Pub.
39. Sanders, H.L., *Marine benthic diversity: a comparative study.* The American Naturalist, 1968. **102**(925): p. 243-282.
40. Gotelli, N.J. and R.K. Colwell, *Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness.* Ecology letters, 2001. **4**(4): p. 379-391.

41. Hoagland, B.W. *Woody species composition of floodplain forests of the Little River, McCurtain and LeFlore Counties, Oklahoma*. in *Proceedings of the Oklahoma Academy of Science*. 1996.

42. Parthasarathy, N., *Changes in forest composition and structure in three sites of tropical evergreen forest around Sengaltheri, Western Ghats.* Current science, 2001: p. 389-393.

43. Chazdon, R.L., et al., *Community and phylogenetic structure of reproductive traits of woody species in wet tropical forests.* Ecological monographs, 2003. **73**(3): p. 331-348.

44. Singh, J. and S. Singh, *Forest vegetation of the Himalaya.* The Botanical Review, 1987. **53**(1): p. 80-192.